



(11) **EP 1 538 231 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention  
of the grant of the patent:  
**25.08.2010 Bulletin 2010/34**

(51) Int Cl.:  
**C22C 38/44** <sup>(2006.01)</sup> **C21D 1/18** <sup>(2006.01)</sup>  
**C21D 9/34** <sup>(2006.01)</sup>

(21) Application number: **04016413.9**

(22) Date of filing: **13.07.2004**

(54) **A microalloy bainitic steel with high resistance to fatigue and to fretting fatigue**

Mikrolegierter bainitischer Stahl mit hoher Ermüdungsfestigkeit

Acier bainitique microalliée hautement résistante à la fatigue

(84) Designated Contracting States:  
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR  
HU IE IT LI LU MC NL PL PT RO SE SI SK TR**

(30) Priority: **03.12.2003 IT mi20032370**

(43) Date of publication of application:  
**08.06.2005 Bulletin 2005/23**

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**FR-A- 2 166 585 GB-A- 1 417 330**  
**US-A- 5 518 685 US-A- 5 533 770**

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**Description**Field of the invention

**[0001]** The present invention refers to a microalloy bainitic steel with high resistance to fatigue and to fretting fatigue.  
**[0002]** More particularly, the present invention refers to a microalloy bainitic steel with high resistance to fatigue and to fretting fatigue being particularly suitable to be used for the manufacturing of rail wheels, i.e. wheels for railway, tramway and/or metro fields.

Description of the prior art

**[0003]** It is known that the wheel is one of the most important components making the rolling stock. During the running of the vehicle, the wheel is submitted to complex phenomena such as ratchetting, fretting fatigue wear friction, etc. intervening on the wheel/rail interface. In fact, during the wheel/rail contact on a thin layer of material placed immediately under the contact area, great stresses occur due to the severe load conditions. These stresses give rise both to the first stages of fretting fatigue failures and to wearing.

**[0004]** Fatigue failures are very dangerous as they can cause the detachment of small portions of wheel, with serious consequences both on suspensions, on the axle-box bearings of the vehicle and on the railway infrastructure.

**[0005]** According to the working conditions, fretting fatigue failures can be spallings due to ratchetting phenomena or to heat loads or spallings due to shellings or deep shellings.

**[0006]** In the first case, spallings are induced by cold ratchetting. It is known that the wheel/rail contact develops in cyclic elastic-plastic conditions with localized ratchetting and the sum of ratchetting deriving from various cycles may give rise to local failures for damage accumulation.

**[0007]** In the second case, spallings are due to the detachment of small portions of wheels with cratering forming on the rolling surface in conditions of high axle loads or in the presence of macrodefects at depths comprised between 6 and 30 mm under the rolling surface.

**[0008]** Steels with high resistance levels are known on the market, they successfully remove the drawbacks due to wearing phenomena, but the problems connected to fretting fatigue failures which constitute an ever higher percentage of the damage phenomena of wheels and rails are still present.

**[0009]** EP-A-1 241 277 on which is based the preamble of claim 1, discloses a steel alloy, particularly for railway wheels, comprising carbon, silicon, manganese as alloying elements imparting hardness, and chromium, nickel, molybdenum, as alloying elements improving the tempering properties, but no elements with microalloying properties.

**[0010]** Both FR-A-2 166 585 and EP-A-0 884 396 disclose the manufacturing of a steel alloy comprising carbon, silicon, manganese as alloying elements imparting hardness, and chromium, nickel, molybdenum, as alloying elements improving the tempering properties, the former document additionally disclosing the use of V in the composition.

**[0011]** EP 0612852 discloses a process for manufacturing high-strength bainitic steel rails with excellent rolling contact fatigue resistance, the steel comprising carbon, silicon, manganese and chromium, and optionally at least one element selected from three groups of elements, namely Ni, Mo, Cu; Nb, V, Ti; B.

**[0012]** The object of the present invention is to remove the above-mentioned drawbacks.

**[0013]** More particularly, the object of the present invention is to provide a steel suitable for the manufacturing of wheels for the railway, tramway and/or metro fields having a high resistance to fretting fatigue failures.

**[0014]** A further object of the present invention is to provide a steel suitable for the manufacturing of wheels for the railway, tramway and/or metro fields having high mechanical resistance and toughness features combined with high resistance features to wearing and fretting fatigue.

**[0015]** According to the present invention these and other objects, that will be clear from the following description, are obtained by a steel alloy as claimed in claim 1.

**[0016]** The presence of small amounts of microalloying elements in well defined ratios among them and compared with the other steel elements helps the steel hardening and protects its toughness. These elements with microalloying properties are Nb, Zr, Al and Ti in quantities not higher than 0.06% by weight for each element and B, Ca and N in quantities not higher than 0.007% by weight, for each element.

**[0017]** A steel according to an embodiment of the present invention preferably comprises:

|           |              |           |
|-----------|--------------|-----------|
| Carbon    | 0.15 - 0.35% | by weight |
| Silicon   | 0.60 - 1.20% | by weight |
| Manganese | 0.60 - 1.50% | by weight |
| Chromium  | 0.10 - 1.00% | by weight |

(continued)

|    |            |                 |           |
|----|------------|-----------------|-----------|
|    | Nickel     | 0.10 - 1.00%    | by weight |
|    | Molybdenum | 0.10 - 0.90%    | by weight |
| 5  | Vanadium   | 0.01 - 0.15%    | by weight |
|    | Niobium    | 0.01 - 0.05%    | by weight |
|    | Zirconium  | 0.005 - 0.06%   | by weight |
|    | Aluminium  | 0.005 - 0.06%   | by weight |
| 10 | Titanium   | 0.005 - 0.06%   | by weight |
|    | Boron      | 0.0005 - 0.005% | by weight |
|    | Calcium    | 0.0002 - 0.005% | by weight |
|    | Nitrogen   | 0.003 - 0.007%  | by weight |

15 **[0018]** The remaining part up to 100 being iron without impurities.

**[0019]** After the mechanical machining of the steel of the present invention for the manufacturing of wheels for the railway, tramway and/or metro fields, the product is submitted to austenitization and quenching in water. This process consists in the heating at a temperature comprised between 850 and 950° C, a stay at this temperature for one hour for about each 40 mm of thickness of the processed product and in a quick cooling in water until room temperature is reached.

20 **[0020]** The product is then submitted to two thermal tempering processes in order to attenuate internal stresses caused by the abrupt cooling.

**[0021]** The first thermal tempering process is carried out by heating at a variable temperature comprised between 500 and 700°C according to the required features for a stay time at this temperature of about one hour for each 20 mm of thickness of the processed product, followed by a spontaneous air cooling until room temperature is reached.

25 **[0022]** The second thermal tempering process is carried out by heating at a temperature lower than 20°C compared to the one of the first thermal tempering process for a stay time at this temperature of about one hour for each 20 mm of thickness of the processed product followed by a spontaneous air cooling for at least 25 minutes and in any case being such to cool the rail wheel rolling until room temperature is reached.

**[0023]** The cooling of the rail wheel rolling can be carried out at a different speed from the one used for the cooling of the web in order to give different properties to each part of the wheel.

30 **[0024]** The steel of the present invention is characterized by an excellent balancing between tensile and toughness features. Toughness values are very high at any temperature level.

**[0025]** A clear demonstration of said feature balancing is due to the fact that the ductile/brittle transition temperature, defined by the F.A.T.T. value corresponding to 50% is placed at -40°C even though the tensile stress values are very high.

35 **[0026]** In order to better understand the present invention and put it into practice the following illustrative and non limitative example is given.

#### Example

40 **[0027]** Some castings have been manufactured according to the following objective analysis:

|    |            |                 |           |
|----|------------|-----------------|-----------|
|    | Carbon     | 0.27 - 0.32%    | by weight |
|    | Silicon    | 0.60 - 0.80%    | by weight |
|    | Manganese  | 0.90 - 1.10%    | by weight |
| 45 | Chromium   | 0.20 - 0.50%    | by weight |
|    | Nickel     | 0.20 - 0.50%    | by weight |
|    | Molybdenum | 0.20 - 0.50%    | by weight |
|    | Vanadium   | 0.020 - 0.050%  | by weight |
| 50 | Niobium    | 0.020 - 0.040%  | by weight |
|    | Zirconium  | 0.015 - 0.045%  | by weight |
|    | Aluminium  | 0.015 - 0.055%  | by weight |
|    | Titanium   | 0.010 - 0.040%  | by weight |
|    | Boron      | 0.0010 - 0.040% | by weight |
| 55 | Calcium    | 0.002 - 0.003%  | by weight |
|    | Nitrogen   | 0.003 - 0.004%  | by weight |

[0028] The remaining part up to 100 being iron without impurities.

[0029] With the steels thus obtained some rail wheels have been manufactured according to the prior arts each of them having a rolling diameter of 915 mm.

[0030] Each wheel has been submitted to austenitization and quenching by heating at a temperature of about 900°C for a stay time at this temperature of about 3 hours and a quick cooling in water until room temperature was reached.

[0031] Each wheel was then submitted to two subsequent thermal tempering processes the first of which was carried out by heating at a temperature of about 520°C - 600°C for a stay time at this temperature of about six hours and a spontaneous air cooling until room temperature was reached; the second one was carried out by heating at a temperature of 20°C lower than the one of the first process for a stay time at such temperature of about six hours and a spontaneous air cooling for 60 minutes until room temperature was reached.

[0032] The rail wheels thus obtained had the following average mechanical features:

#### ROLLING SURFACE

[0033]

| PROPERTIES          | STANDARD     | UNIT | VALUE |
|---------------------|--------------|------|-------|
| Monotonic yield     | UNI EN10002  | Mpa  | 1,090 |
| Tensile stress      | UNI EN10002  | Mpa  | 1,210 |
| Elongation at break | UNI EN10002  | %    | 16    |
| Reduction coeff.    | UNI EN 10002 | %    | 55    |
| WEB                 |              |      |       |
| PROPERTIES          | STANDARD     | UNIT | VALUE |
| Monotonic yield     | UNI EN10002  | Mpa  | 1,090 |
| Tensile stress      | UNI EN10002  | Mpa  | 1,210 |
| Elongation at break | UNI EN10002  | %    | 16    |
| Reduction coeff.    | UNI EN10002  | %    | 55    |

#### Claims

1. A microalloy bainitic steel alloy for rail wheels with high resistance to fatigue and to fretting fatigue, comprising: C, Si, Mn, Cr, Ni, Mo,

**characterized in that** it comprises, in weight percentage:

an amount of C comprised between 0.15 and 0.35%,

an amount of Si comprised between 0.6 and 1.20%,

an amount of Mn comprised between 0.6 and 1.50%,

an amount of Cr comprised between 0.10 and 1.00%,

an amount of Ni comprised between 0.10 and 1.00%,

an amount of Mo comprised between 0.10 and 0.90%,

and **in that** it further comprise the following elements having microalloying properties, in weight percentage:

- V in an amount comprised between 0.01 and 0.15%, and

- Nb, Zr, Al, Ti each present in an amount not higher than 0.06%,

- B, Ca and N, each present in an amount not higher than 0.007%,

the remaining part up to 100 being iron, without impurities.

2. A method for manufacturing a rail wheel with high resistance to fatigue and fretting fatigue from a microalloy bainitic steel alloy as claimed in claim 1 comprising the steps of:

mechanically machining said steel alloy;

submitting it to austenitization;

quenching it in water; and

subjecting it to two thermal tempering processes.

3. A method as claimed in claim 2, **characterized in that** said austenitization and quenching in water comprises:

heating the wheel to a temperature between 850°C and 950°C;  
maintaining the wheel at such a temperature for one hour for about each 40 mm of thickness of the processed product;  
quick cooling it in water until room temperature is reached.

4. A method as claimed in claim 2 or 3, **characterized in that** said first thermal tempering process comprises

heating to a temperature between 500 and 700°C,  
maintaining the wheel at such a temperature for about one hour for each 20 mm of thickness of the processed product;  
and air cooling until room temperature is reached.

5. A method as claimed in claims 2 or 3 or 4, **characterized in that** said second thermal tempering treatment comprises:

heating the product to a temperature lower than 20°C compared to the one of the first thermal tempering process;  
maintaining the product at this temperature for about one hour for each 20 mm of thickness of the processed product; and  
air cooling the product for at least 25 minutes, and in any case being such to cool the rail wheel rolling until room temperature is reached.

6. A method as claimed in claim 7, **characterized in that** the cooling of the wheel rolling is carried out at a different speed from the one used for the cooling of the web.

7. A rail wheel manufactured from a microalloy bainitic steel alloy as claimed in claim 1.

## Patentansprüche

1. Mikrolegierter bainitischer Stahl für Laufräder mit hoher Ermüdungsfestigkeit und hoher Kontaktermüdungsfestigkeit mit C, Si, Mn, Cr, Ni und Mo.

**dadurch gekennzeichnet** enthält die Legierung:

zwischen 0,15 und 0,35 % C;  
zwischen 0,6 und 1,20 % Si;  
zwischen 0,6 und 1,50 % Mn;  
zwischen 0,10 und 1,00 % Cr;  
zwischen 0,10 und 1,00 % Ni;  
zwischen 0,10 und 0,90 % Mo.

Außerdem beinhaltet sie die folgenden Mikrolegierungselemente in den nachstehenden Gewichtsanteilen:

zwischen 0,01 und 0,15 % V;  
jeweils höchstens 0,06 % Nb, Zr, Al und Ti;  
jeweils höchstens 0,007 % B, Ca und N,  
die restlichen Anteile auf 100 % bestehen aus reinem Eisen.

2. Eine Methode zur Herstellung eines Laufrads mit hoher Ermüdungsfestigkeit und hoher Kontaktermüdungsfestigkeit mit einer Mikrolegierter bainitischer Stahl nach Anspruch 1, umfasst die folgenden Arbeitsschritte:

mechanische Verarbeitung der oben genannten Stahllegierung;  
Austenitisierung;  
anschließendes Abschrecken in Wasser und  
abschließend zweimaliges Anlassen durch Wärmebehandlung.

3. Eine Methode nach Anspruch 2, die sich dadurch auszeichnet, dass die genannten Vorgänge der Austenitisierung und des Abschreckens folgende Schritte beinhalten:

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Erhitzen des Rads auf eine Temperatur zwischen 850 C und 950 C;  
Durchwärmung des Rads bei dieser Temperatur für eine Stunde pro 40 mm Stärke des bearbeiteten Erzeugnisses;  
rasche Abkühlung in Wasser bis zur Erreichung der Raumtemperatur.

- 5  
4. Eine Methode nach Anspruch 2 oder 3, die sich dadurch auszeichnet, dass der genannte erste Anlassvorgang folgende Schritte beinhaltet:

10  
das Aufheizen auf eine Temperatur zwischen 500 und 700 C;  
die Durchwärmung des Rads bei dieser Temperatur für eine Stunde pro 20 mm Stärke des bearbeiteten Erzeugnisses  
und die anschließende Luftkühlung bis zur Erreichung der Raumtemperatur.

- 15  
5. Eine Methode nach Anspruch 2 oder 3 oder 4, die sich dadurch auszeichnet, dass der genannte zweite Anlassprozess folgende Schritte beinhaltet:

20  
Erhitzen des Erzeugnisses auf eine Temperatur, die 20 C unter der des ersten Anlassvorgangs liegt;  
Durchwärmung des Rads bei dieser Temperatur für eine Stunde pro 20 mm Stärke des bearbeiteten Erzeugnisses;  
sowie die anschließende Kühlung des Erzeugnisses für mindestens 25 Minuten und in jedem Fall so lange, bis das Wälzlager Raumtemperatur erreicht hat.

- 25  
6. Eine Methode nach Anspruch 5, die sich dadurch auszeichnet, dass das Kühlen des Wälzlagers bei einer unterschiedlichen Geschwindigkeit als jener durchgeführt wird, die für das Kühlen der Laufschiene verwendet wird.

7. Ein Laufrad, das mit einer Mikrolegierter bainitischer Stahl laut Anforderung 1 hergestellt wird.

### Revendications

- 30  
1. Acier bainitique microallié pour roue ferroviaire haute résistance à l'usure et au frottement, contenant : C, Si, Mn, Cr, Ni, Mo,  
**caractérisé en ce que** comprendre en pourcentage de poids:

35  
une quantité de C comprise entre 0.15 et 0.35 %,  
une quantité de Si comprise entre 0.6 et 1.20%,  
une quantité de Mn comprise entre 0.6 et 1.50%,  
une quantité de Cr comprise entre 0.10 et 1.00%,  
une quantité de Ni comprise entre 0.10 et 1.00%,  
40  
une quantité de Mo comprise entre 0.10 et 0.90%,  
et **en ce que** comprendre de plus les éléments suivants, ayant des propriétés de microalliage, en pourcentage de poids :

- 45  
- V dans une quantité comprise entre 0.01 et 0.15%, et  
- Nb, Zr, Al, Ti, chacun présent dans une quantité non supérieure à 0.06%,  
- B, Ca et N, chacun présent dans une quantité non supérieure à 0.007%,

le reste jusque à 100 parties étant composé de fer sans impureté.

- 50  
2. Méthode de fabrication de une roue ferroviaire haute résistance à l'usure et au frottement d'après un alliage d'acier bainitique microallié selon la revendication 1, comprenant les étapes de :

usinage mécanique dudit alliage d'acier ;  
austénisation de l'alliage ;  
55  
trempe à l'eau ; et  
soumission de l'alliage à deux traitements thermiques de revenu.

3. Méthode selon la revendication 2, **caractérisée en ce que** ladite austénisation et la trempe à l'eau comprennent :

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le chauffage de la roue à une température comprise entre 850°C et 950°C ;  
le maintien à cette température de la roue pendant une heure pour chaque 40 mm d'épaisseur du produit traité ;  
refroidissement rapide à l'eau jusqu'à la température ambiante.

- 5     **4.** Méthode selon la revendication 2 ou 3, **caractérisée en ce que** ledit premier traitement thermique de revenu comprend :

10           le chauffage à une température comprise entre 500 et 700°C,  
          le maintien à cette température de la roue pendant environ une heure pour chaque 20 mm d'épaisseur du produit traité ;  
          et refroidissement à l'air jusqu'à la température ambiante.

- 15     **5.** Méthode selon la revendication 2 ou 3 ou 4, **caractérisée en ce que** ledit second traitement thermique de revenu comprend :

          le chauffage du produit à une température plus basse de 20°C par rapport à celle du premier traitement par revenu thermique ;  
          le maintien à cette température du produit pendant environ une heure pour chaque 20 mm d'épaisseur du produit traité ; et  
20       refroidissement à l'air du produit pendant au moins 25 minutes, et dans tous les cas de façon à refroidir le laminage de la roue ferroviaire jusqu'à la température ambiante.

- 25     **6.** Méthode selon la revendication 5, **caractérisée en ce que** le refroidissement de la roue ferroviaire est effectué à une vitesse différente de celle utilisée pour refroidir la toile.

- 30     **7.** Roue ferroviaire fabriquée d'après un alliage d'acier bainitique microallié selon la revendication 1.

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**REFERENCES CITED IN THE DESCRIPTION**

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